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IBM United Kingdom Limited Intellectual  
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(57) The objective lens 34 of an optical disk drive has a suitable positioning and numerical aperture so that the light beam will be focused into a spot on the optical media of a first optical disk 36 having a cover plate with a first thickness. When a second optical disk is utilized having a cover plate with a second thickness different from the first thickness, a liquid crystal compensator lens 48 is actuated in the optical path between the light source and the objective

lens for focusing the light beam into a spot on the optical media of the second optical disk. A correction signal may be applied to the liquid crystal in the compensator lens for altering a refractive index thereof. This substantially eliminates a wavefront aberration in the reflected light beam which would otherwise occur if the beam were focused onto the optical media of the second optical disk solely by use of the objective lens.

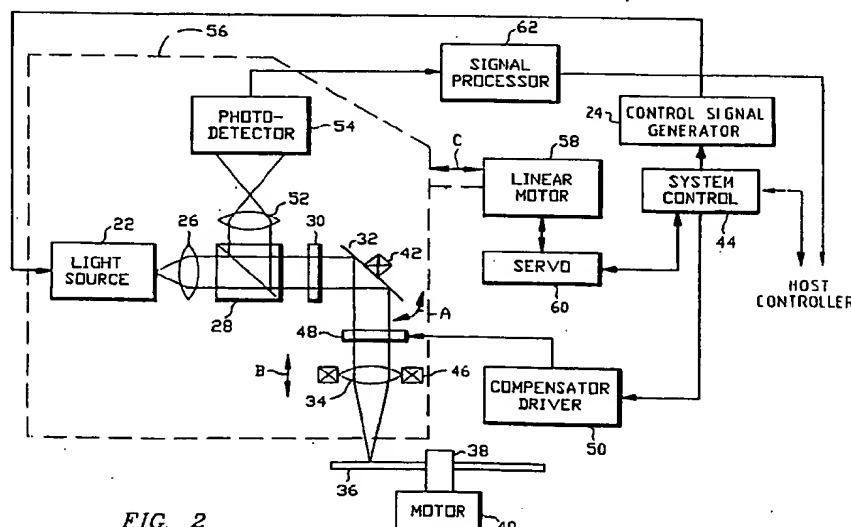


FIG. 2

The present invention relates to optical disk drives for data storage, and more particularly, those for use with optical disks having a thin transparent layer to protect the recording surface from scratches and contamination.

Optical disk drive systems are widely used in audio, video and computer-related applications. Typically a laser beam is modulated by a pulse signal from an information source in order to record the information in binary form on the surface of the disk made of a special media. In a write-once-read-mostly (WORM) optical disk drive system the drive can write information onto the disk which cannot later be re-written. Small regions of the disk media which are arranged in concentric or spiral tracks are physically altered by the laser beam, such as by heating. The information recorded can be read by reflecting a laser beam off the surface at a low power so as not to physically alter the small regions. The disk may be impressed with radial servo-tracking information, data-synchronization signals and pre-formatting to provide positioning information for the optical head. CD ROM drives are similar to WORM drives except that the former can only read pre-recorded optical media. They have no capability for writing. More recently, erasable optical disk drive systems have been developed. They permit information to be temporarily written on the disk media and either erased or written over. Such systems require magneto-optic (MO) media and rely upon the so-called Kerr effect. When light is reflected from a film of magnetized magneto-optic material the light has its plane of polarization rotated.

Optical disks which have come into wide spread use have typically included a transparent protective layer or so-called cover plate to protect the recording surface of the underlying optical media from scratches and contamination. Glass or plastic are commonly used as the cover plate. One standard thickness of the cover plate is 1.2 mm. Surface defects or contamination on the cover plate do not normally introduce errors because they are not in the focal plane of the objective lens in the optical head. The objective lens is typically designed to correct the spherical aberration induced by the 1.2 mm cover plate.

Currently, objective lenses utilized in commercially available optical disk drive systems have a 0.55 numerical aperture and are corrected for a 1.2 mm cover plate thickness. In the future, the numerical aperture will be increased to increase the data storage density. As the numerical aperture increases, the tolerances on disk tilt are correspondingly reduced. For example, the increasing of the numerical aperture from 0.55 to 0.65 requires the disk tilt tolerance to be reduced by a factor of 1.65. However, the disk tilt tolerances are also

proportional to the thickness of the optical disk. Thus, if the thickness of the disk cover plate could be reduced from 1.2 mm to, for example, 0.6 mm, the disk tolerances could remain as specified in the current industry specification or even be relaxed by 15%.

Designing an objective lens in an optical head to work with a 0.6 mm cover plate would prevent it from reading or writing with respect to an optical disk having a 1.2 mm cover plate. This is because of the uncorrected spherical aberration resulting from the 0.6 mm uncompensated portion of the cover plate thickness. Fig. 1 illustrates the wavefront aberrations introduced by focusing a laser beam corrected for a 0.6 mm cover plate through a 1.2 mm cover plate utilizing a 0.65 numerical aperture objective lens. The wavefront has approximately three waves of aberration measured from peak-to-valley. The vertical axis represents units of optical wavefront error in wavelengths of 830 nanometers. The horizontal axis represents normalized pupil coordinates.

It is possible to mechanically insert a glass plate into the path of the laser beam when interchanging optical disks having different cover plate depths. In other words, the optical disk drive system can incorporate an objective lens designed for a thick cover plate. The same optical disk drive system can then operate with optical disks having a thinner cover plate by physically adding the equivalent of a second cover plate to make up the missing cover plate depth. However, such a solution is unsatisfactory because the electro-mechanical devices which are necessary are not compatible with reproducible (tilt-free) insertion and long-term reliability of the system. Also, this method would be too slow and mechanically complex for cascaded systems designed to read data stored on multiple layers of a disk.

Accordingly, the invention provides an optical disk drive for use with an optical disk comprising an optical media for data storage with a transparent protective coating, said optical disk drive including:

- means for generating a light beam for reflection off the surface of the optical media of the disk;
- an objective lens for focusing the light beam onto the optical media for a disk with a transparent protective coating having a first thickness;

- and characterised by compensation lens means selectively actuable in conjunction with the objective lens to focus the light beam onto the optical media of a disk with a transparent protective coating having a thickness different from said first thickness.

Such an optical disk drive system permits interchangeable use of optical disks having different cover plate depths.

In a preferred embodiment, the compensation lens means includes a compensator lens containing a quantity of liquid crystals and means for applying a correction signal to the liquid crystals for altering a refractive index of the liquid crystals to eliminate wavefront aberration at the surface of the optical media. The compensator lens includes:

transparent means for containing the liquid crystals;

means for aligning the liquid crystals to change an index of refraction thereof upon the application of a correction signal; and

electrode means connected to the alignment means for applying the correction signal thereto.

It is further preferred that the compensator lens comprises a laminated structure including:

upper and lower spaced-apart transparent substrates and means for joining the edges of the substrates to seal the liquid crystals therebetween.

transparent electrodes overlying the opposing faces of the substrates; and

upper and lower liquid crystal alignment films overlying opposing faces of the electrodes.

Preferably a surface profile of the lower liquid crystal alignment film is complementary to a wavefront aberration in the light beam that would be reflected off the optical media of an optical disk with a protective coating having a second thickness in the absence of said compensator lens means. Typically the surface profile of the lower liquid crystal alignment film is approximately sinusoidal.

In a preferred embodiment each electrode comprises a transparent electrode film in contact with a corresponding liquid crystal alignment film, the electrodes are made of Indium-Tin-Oxide, and the liquid crystals are selected from the group consisting of nematic liquid crystals and smectic liquid crystals.

From one aspect therefore a mechanism is provided for rotating an optical disk about a drive axis. A light beam from a source is focused into a spot on an underlying optical media of the disk. Light reflected from the optical media is received by a photo-detector and information encoded on the media is recovered therefrom. The objective lens has a suitable positioning and numerical aperture so that the light beam will be focused into a spot on the optical media of a first optical disk having a cover plate with a first thickness. When a second optical disk is utilized having a cover plate with a second thickness different from the first thickness, a compensator lens is actuated in the optical path between the light source and the objective lens for focusing the light beam into a spot on the optical media of the second optical disk. The compensator lens may comprise a laminated structure of transparent substrates, liquid crystal alignment films and electrodes which enclose a

quantity of liquid crystal material. A correction signal may be applied to the liquid crystal material for altering a refractive index thereof. This substantially eliminates a wavefront aberration in the reflected light beam which would otherwise occur if the beam were focused onto the optical media of the second optical disk solely by use of the objective lens.

An embodiment of the invention will now be described by way of example with reference to the following drawings:

Fig. 1 is a graph illustrating the wavefront aberration in the tangential plane for a laser beam corrected for a 0.6 mm cover plate utilizing a 0.65 numerical aperture objective lens but instead reflected through a 1.2 mm cover plate.

Fig. 2 is a combination diagrammatic view and functional block diagram of an optical disk drive in accordance with the present invention; and

Fig. 3 illustrates a cross-section of a compensator lens that may be used in the optical disk drive of Figure 2 (this figure is not drawn to scale).

Referring to Fig. 2, a light source 22 such as a laser is energized by a control signal generator 24. The light beam from the light source 22 is transmitted through a lens 26, a beam splitting prism 28, and a quarter-wave plate 30 to a galvano-mirror 32. The light beam is reflected by the galvano-mirror 32 and focused by an objective lens 34 onto an optical disk 36. The optical disk 36 is supported by a spindle 38 connected to a motor 40 for rotating the disk about a drive axis perpendicular to the plane of the disk. The galvano-mirror 32 is pivotally mounted and moveable through an angle illustrated by the double arrow labeled A in Fig. 2. This movement of the galvano-mirror is accomplished via solenoid 42 to move the light beam in a radial direction on the disk in order to follow an information track encoded thereon. The solenoid 42 is driven by a servo circuit (not illustrated) connected to a system control 44.

The objective lens 34 is moved toward and away from the disk 36 as illustrated by the double arrow labeled B in Fig. 2. This movement of the objective lens along an axis perpendicular to a plane of the disk 36 is accomplished by means of a solenoid 46 energized by another servo circuit (not illustrated) connected to the system control 44.

The optical disk 36 comprises a conventional underlying optical media and an overlying cover plate of either plastic or glass having a thickness of, for example, 0.6 mm. The objective lens 34 is moved toward and away from the optical disk 36 in order to focus the light beam into a spot on the optical media. Information is encoded on the media in binary form in concentric tracks or in a spiral track. In one conventional form of optical media,

the data is encoded as a succession of pits and islands which correspond to ones and zeros.

In accordance with our invention, a compensator lens 48 is imposed in the path of the collimated light beam between the objective lens 34 and the galvano-mirror 32. As will be explained in greater detail hereafter, the compensator lens 48 is utilized to correct wavefront aberrations introduced by focusing the light beam corrected for a 0.6 mm cover plate through a 1.2 mm cover plate on a different optical disk loaded into the system in lieu of the optical disk 36. The compensator lens 48 is actuated by a correction signal from a compensator driver circuit 50 connected to the system control 44. The system control 44 also commands the control signal generator 24 which drives the light source 22.

The light beam reflected from the optical disk 36 is passed through the objective lens 34, through the compensator lens 48, and back to the galvano-mirror 32. The mirror reflects the light beam through beam-splitting prism 28 via the quarter-wave plate 30. The beam splitting prism 28 reflects the beam through lens 52 to a photo-detector 54. The elements enclosed by the phantom line in Fig. 2 reside in an optical head 56. This head is moved radially across the disk for track selection as illustrated by the double arrow labeled C in Fig. 2. This movement is accomplished utilizing a linear motor 58 driven by a servo circuit 60 connected to the system control 44.

The photo-detector 54 comprises a suitable transducer, such as a photo-diode, for detecting the intensity of light in the reflected beam. The output signal from the detector 54 is sent to a signal processor 62 which generates data signals representative of the information encoded on the optical media and sends them to a host controller. The system control 44 of the optical disk drive system is also under command of the host controller.

Fig. 3 illustrates details of the compensator lens 48. Light passes through this lens in the direction of the large arrows in Fig. 3. It comprises a laminated structure including upper and lower substrates 70 and 72, upper and lower crystal alignment films 74 and 76, a layer of nematic or smectic liquid crystals 78, and upper and lower transparent electrodes 80 and 82. When energized, these electrodes align the liquid crystals in order to alter the index of refraction of the compensator lens 48. The electrodes 80 and 82 are connected to leads 84 and 86 which connect to the compensator driver 50 (Fig. 2). The side edges of the laminated structure are held together by layers of epoxy 88 and 90. The epoxy seals together the spaced apart substrates to provide a container for the liquid crystals.

The lower crystal alignment film 76, the lower electrode 82, and the lower substrate 72 are configured to give them a shape which is complementary to the wavefront aberration curve 92 illustrated in phantom lines. The refractive index of the lower substrate 72 is equal to the zero voltage state of the liquid crystals 78. Thus, with no applied voltage the alignment films 74 and 76 do not modify the wavefront. When the compensator driver 50 applies the appropriate voltage, the refractive index of the crystals changes. This change in refractive index  $\Delta n$  is between 0.05 and 0.30 depending upon the type of liquid crystals utilized.

The liquid crystal alignment films 74 and 76 may be made of polyvinyl alcohol and may have a thickness of, for example, ten nanometers. The upper and lower substrates 70 and 72 may be made of any high optical quality transparent plastic or glass and may have a thickness of, for example, one to five millimeters. The transparent electrodes 80 and 82 may each comprise a continuous film layer of Indium-Tin-Oxide and may have a thickness of, for example, fifty nanometers. The wavefront profile in the lower substrate 72 may be formed by press molding. The surface profile of the substrate 72 may also be achieved by ion milling or patterned thin film deposition. In the preferred embodiment, the distance illustrated by the double arrow labeled D in Fig. 3 from peak to valley equals approximately 17.7 microns. The thickness of the layer of liquid crystals 78 may be approximately twenty microns at its thickest point. The voltage level of the correction signal which must be applied by the compensator driver 50 to sufficiently alter the index of refraction depends upon the type of liquid crystal material. The inwardly facing surfaces of the alignment films 74 and 76 can have greater roughness than if they were exposed to air since the liquid crystal layer acts as an index matching liquid.

The liquid crystal response,  $\Delta n$ , must be proportional to the electric field to the power of  $x$  where  $x$  does not equal one. The refractive index of nematic liquid crystals varies as the square of the electric field. If the response is linear in the electric field, the refractive index is higher for thinner sections because the electric field is stronger. If the liquid crystal layer 78 is driven to saturation this will insure the refractive index is constant across the compensator lens 48 regardless of the electric field distribution. The change in wavefront aberration from the OFF state to the ON state may be expressed as the product of  $\Delta n$  times  $S(x,y)$  divided by  $\lambda$ , (the wavelength of the incident light).  $S(x,y)$  defines the surface profile of the lower crystal alignment film 76.  $S(x,y)$  is generally of the form  $S(x,y) = \alpha_1(x^2 + y^2) + \alpha_2(x^2 + y^2)^2 + \alpha_3(x^2 + y^2)^3$ . Assuming  $\Delta n$  equals 0.15 and  $\lambda$

equals 0.83 microns, the surface profile,  $S(x,y)$  should have the same cross-section as the generally sinusoidal curve in the graph of Fig. 1, but with a peak to valley distance of 17.7 microns.

For this particular application, the switching speed of the compensator lens is not critical. It need only turn ON when an optical disk having a thicker cover plate is inserted, and turn OFF when that disk is removed from the disk drive system. The system control 44 can turn the compensator lens 48 ON automatically or through a manual actuator key pushed by an operator when changing optical disks.

The invention is also applicable to magneto-optic (MO) disk drives. One possible location for the compensator lens in an MO system would be between the laser collimator lens and the first beam splitter.

#### Claims

1. An optical disk drive for use with an optical disk (36) comprising an optical media for data storage with a transparent protective coating, said optical disk drive including:

means (22) for generating a light beam for reflection off the surface of the optical media of the disk;

an objective lens (34) for focusing the light beam onto the optical media for a disk with a transparent protective coating having a first thickness;

and characterised by compensation lens means (48, 50) selectively actuatable in conjunction with the objective lens to focus the light beam onto the optical media of a disk with a transparent protective coating having a thickness different from said first thickness.

2. An optical disk drive according to claim 1 wherein the compensation lens means includes a compensator lens (48) containing a quantity of liquid crystals (78) and means (80, 82, 84, 86) for applying a correction signal to the liquid crystals for altering a refractive index of the liquid crystals to eliminate wavefront aberration at the surface of the optical media.

3. An optical disk drive according to claim 2, wherein the compensator lens includes:

transparent means (70, 72, 88, 90) for containing the liquid crystals;

means for aligning (74, 76) the liquid crystals to change an index of refraction thereof upon the application of a correction signal; and

electrode means (80, 82) connected to the alignment means for applying the correction signal thereto.

4. An optical disk drive according to claim 3 wherein the compensator lens comprises a laminated structure including:

upper and lower spaced-apart transparent substrates (70, 72) and means (88, 90) for joining the edges of the substrates to seal the liquid crystals therebetween.

transparent electrodes (80, 82) overlying the opposing faces of the substrates; and

upper and lower liquid crystal alignment films (74, 76) overlying opposing faces of the electrodes.

5. An optical disk drive according to claim 4 wherein a surface profile of the lower liquid crystal alignment film is complementary to a wavefront aberration (92) in the light beam that would be reflected off the optical media of an optical disk with a protective coating having a second thickness in the absence of said compensator lens means.

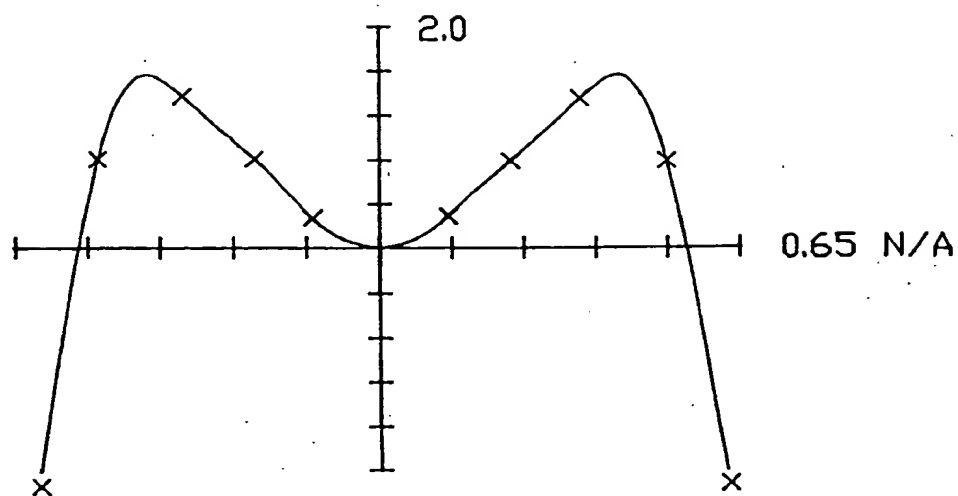
6. An optical disk drive according to claim 5, wherein the surface profile of the lower liquid crystal alignment film is approximately sinusoidal.

7. An optical disk drive according to any of claims 2 to 6, wherein each electrode comprises a transparent electrode film in contact with a corresponding liquid crystal alignment film.

8. An optical disk drive according to claim 6 wherein the electrodes are made of Indium-Tin-Oxide.

9. An optical disk drive system according to any of claims 2 to 8, wherein the liquid crystals are selected from the group consisting of nematic liquid crystals and smectic liquid crystals.

10. A compensator lens means for use in the optical disk drive of any preceding claim.



WAVEFRONT ERROR VS. NORMALIZED PUPIL COORDINATES

FIG. 1

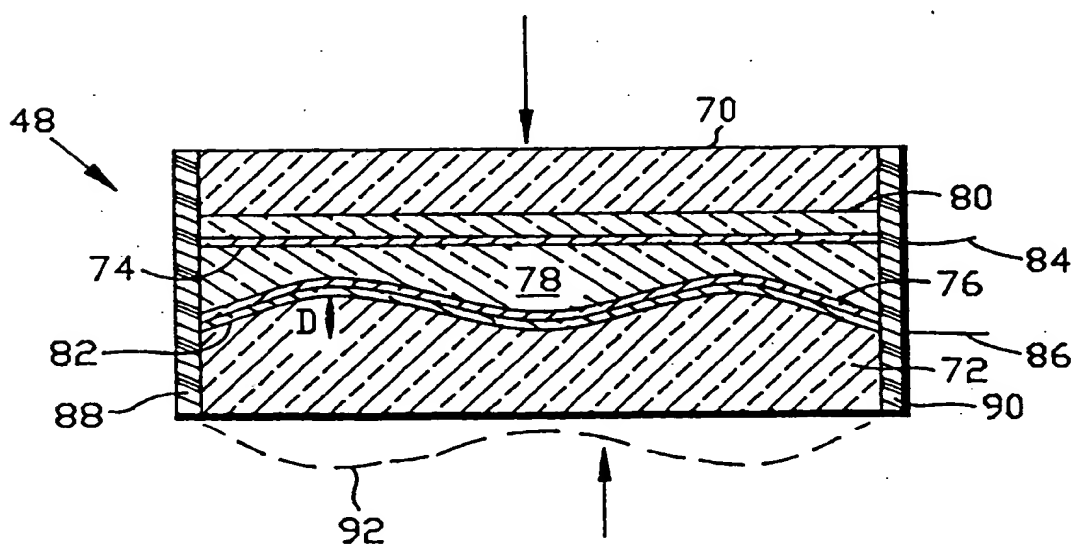


FIG. 3

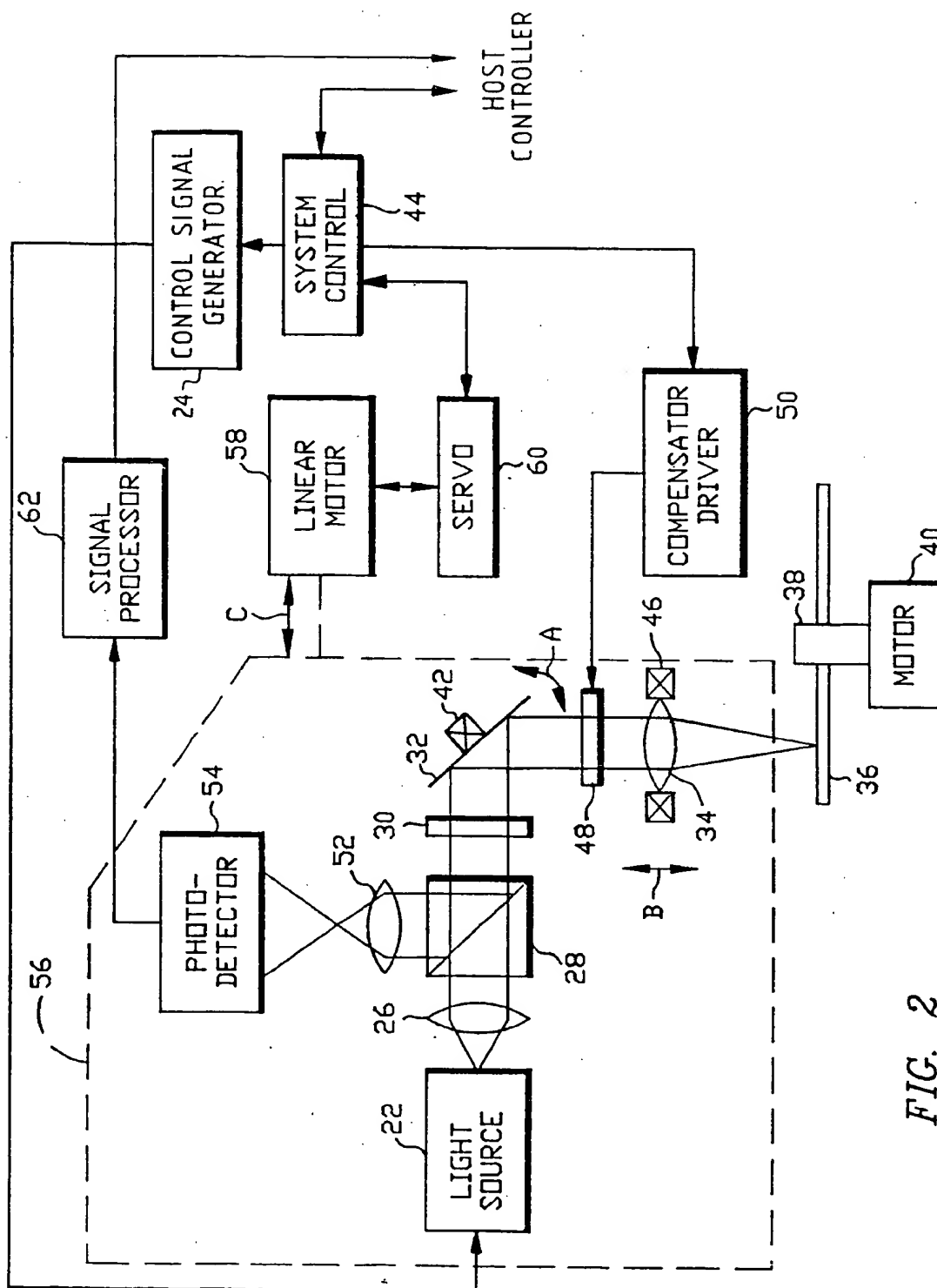


FIG. 2



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Optical disk drive.

The objective lens 34 of an optical disk drive has a suitable positioning and numerical aperture so that the light beam will be focused into a spot on the optical media of a first optical disk 36 having a cover plate with a first thickness. When a second optical disk is utilized having a cover plate with a second thickness different from the first thickness, a liquid crystal compensator lens 48 is actuated in the optical path between the light source and the objective

lens for focusing the light beam into a spot on the optical media of the second optical disk. A correction signal may be applied to the liquid crystal in the compensator lens for altering a refractive index thereof. This substantially eliminates a wavefront aberration in the reflected light beam which would otherwise occur if the beam were focused onto the optical media of the second optical disk solely by use of the objective lens.

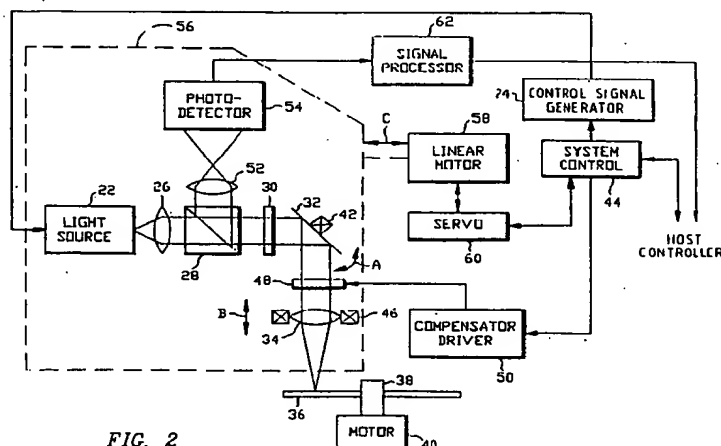


FIG. 2





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## EUROPEAN SEARCH REPORT

Application Number

EP 92 30 8417

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 446 949 (CITIZEN WATCH CO. LTD) * column 3 - column 6; figure 1 *	1-3	G11B7/135 G02B27/00
A	EP-A-0 414 380 (MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD) * column 4 - column 5 *	1	
A	US-A-4 737 946 (T. YAMASHITA) * column 2; figure 20 * * column 11 *	1	
A	PATENT ABSTRACTS OF JAPAN vol. 2, no. 32 (P)28 February 1978 & JP-A-52 153 705 ( MITSUBISHI DENKI .KK ) * abstract *	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 29 MARCH 1993	Examiner SZUBERT J.M.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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